Coronary Arteriography

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• **The rapid injection of opaque media through a large bore, closed-end, side-hole catheter positioned adjacent to the sinuses of Valsalva reliably opacifies the coronary arteries. The potential toxicity of a rapidly introduced large volume of contrast agent and the necessity of peripheral arteriotomy are drawbacks of this procedure.**

Such innovations as loop-ended catheters, balloon occlusion of the aorta, percutaneous arterial catheterization and acetylcholine cardiac arrest have been introduced as attempts are made to increase the reliability and safety of coronary arteriography.

A NEED FOR X-RAY visualization of the cardiac vessels has been stimulated by the development of surgical treatment of coronary artery disease. Evaluation of patients being considered for endarterectomy should include the localization of the occluding atheromata, which can best be accomplished by angiography.[4,20]

Thoracic aortography, wherein contrast material is deposited in the ascending aorta, often delineates the coronary arteries to some extent.[13,19,28] Various methods of administration of the contrast agent have been employed, including needles directed from various sites (sternal,[32] parasternal,[26] transcarotid[24]) or catheters inserted through various arteries (radial,[6,19] brachial,[39] femoral[15]). The use of needles has resulted in cardiac arrhythmias, aortic tearing, extravascular injection and mediastinal hemorrhage. Although using the larger catheters requires peripheral arteriotomy, they have proven to be less dangerous than the needles.

Regardless of the route of administration, the contrast material is swept away within two or three cardiac cycles by the high speed aortic bloodstream. To increase the probability of coronary opacification a high rate of contrast injection is required. The rate of flow of the contrast fluid is proportional to the fourth power of the catheter diameter and to the pressure of injection. It is inversely proportional to the fluid viscosity and catheter length. Thus, to increase the injection rate a maximum catheter diameter is most important. Increasing the diameter from 1 mm. to 3 mm. makes possible an 81-fold increase in flow rate.

In our present method of coronary arteriography a 3 mm. inside diameter radiopaque catheter is introduced through a femoral arteriotomy and under fluoroscopic observation the tip is positioned adjacent to the sinuses of Valsalva. At this point, 0.7 cc. per kg. of 50-70 per cent iodinated contrast medium, heated to body temperature to reduce viscosity, is introduced under a pressure of 6 kg. per cm.^{2} with an automatic injector. The catheter has several small spirally arranged side holes near the closed tip[15] to reduce recoil and give better distribution of the opaque medium. A flow rate of 60-90 cc. per second is achieved. The coronary arteries thus opacified are recorded by simultaneous biplane x-ray exposures taken at the rate of 6 per second.

By this method dependable coronary visualization results. Figure 1, for example, shows a coronary angiogram in which 45 cc. of Ditriokon® was introduced in 0.7 second. The patient is a 43-year-old

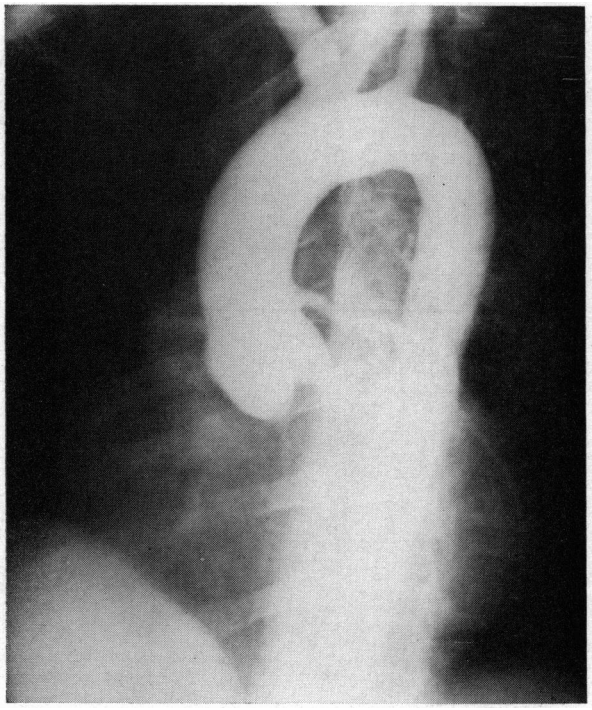

Figure 1.—Coronary arteriogram of a patient with angina pectoris. The right coronary artery is occluded near its origin and the left is narrowed at its bifurcation.

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man with diabetes who had had myocardial infarction five years previously and had had disabling angina for two years. The angiogram showed that the right coronary artery was occluded near its origin and that there was a narrowing of the left coronary at the bifurcation. These observations were confirmed on the following day when endarterectomy was performed on the occluded right coronary artery.

While this technique of angiography does give visualization of the coronary arteries, it entails the inconvenience of peripheral arteriotomy and the significant danger of toxicity associated with injection of contrast media.

In an analysis of over 1,700 thoracic aortographic examinations performed with organic iodides, Abrams[1] noted a 1.7 per cent mortality and a similar percentage of severe reactions including hemiplegia, convulsions and anuria. There were eight times as many deaths associated with the use of 70 per cent contrast solutions as with the 30 to 50 per cent solutions.

Experimental studies[14,16,27] have shown that all the currently available angiographic contrast media produce some toxic effects when used for coronary visualization.

Since the pioneer experiments in 1932 by Rousthoi[34] in Germany and Reboul and Racine[33] in France, a number of investigators[12,22,31] have attempted to improve coronary arteriography in experimental animals. Direct catheterization of the individual coronary arteries is feasible in dogs,[40] and has recently been achieved in humans by Sones.[38] The method requires considerable technical skill and is associated with the possible hazard of coronary ostia occlusion. The individual sinuses of Valsalva, however, may be catheterized with less danger, thereby achieving selective opacification of the right and left coronary arteries.

Loop-End Catheter

Williams and coworkers,[41] using a polyethylene catheter with a perpendicular loop at the end, produced detailed coronary angiograms. With the loop positioned above the aortic sinuses, three side holes in the circumference emit streams of opaque media directed toward the coronary ostia. The curved end is straightened over a guide wire for introduction by way of a peripheral artery. While this ingenious device shows considerable promise, there is some danger of blood clotting in the catheter beyond the proximal side holes, causing embolization.

Balloon Occlusion

One method of overcoming the aortic blood flow and reducing the amount of contrast material is aortic occlusion. A metal sound with a distensible balloon just above the coronary ostia was originally developed by Agress.[2] A similar device introduced through the carotid artery was applied to coronary arteriography by Cannon[5] and McFall.[25] The use of a balloon occlusion catheter by Dotter and coworkers[7] resulted in excellent coronary studies in dogs, but attempts at human application have been frustrating. It is difficult to maintain the position of the balloon in the aortic bloodstream and sometimes it tends to herniate through the aortic valves or occlude the coronary ostia. Increased cardiac work associated with hypertension proximal to the balloon might prove dangerous in patients with coronary insufficiency. Another disadvantage is that it necessitates an arterial cut-down big enough for the relatively bulky balloon catheter.

Cardiac Arrest

A promising technique is that of coronary visualization during pharmacologically induced cardiac arrest. Acetylcholine has proven to be the ideal agent for this purpose. When introduced into the proximal ascending aorta it produces almost immediate cardiac arrest in diastole. An asystole of a few seconds' duration is reliably controlled by the dose administered. As the drug is inactivated by tissue contact, cardiac contraction resumes and, after a fleeting partial heart block, regular sinus rhythm is reestablished. If necessary the action of acetylcholine can be stopped instantaneously by atropine, the ideal antidote.

The investigations of Dotter and coworkers,[7] Arnulf,[3] and Fabrikant and coworkers[10] have shown acetylcholine arrest to be safe and reliable in dogs with normal and ischemic hearts. Electrocardiographic monitoring, serum transaminase determinations and histologic examinations have failed to detect any significant myocardial alterations following repeated episodes of acetylcholine arrest. Our own observations confirm the safety of this procedure in the experimental animal.

This technique would seem to offer several advantages. The coronary arteries which normally fill during diastole show excellent filling during arrest and a capillary filling phase appears which delineates the myocardial walls. A smaller amount of less concentrated contrast material can be used, thus greatly reducing one of the primary hazards of this procedure. And since the extremely rapid flow of contrast is not required, a smaller catheter may be introduced percutaneously,[8,30,35] thus obviating the necessity of arterial cut down. During cardiac arrest there is no need for rapid sequence filming, short exposures and precise exposure timing. Hence, no special x-ray equipment is required.

Acetylcholine, which causes peripheral vasodilatation, apparently does not inhibit coronary spasm.

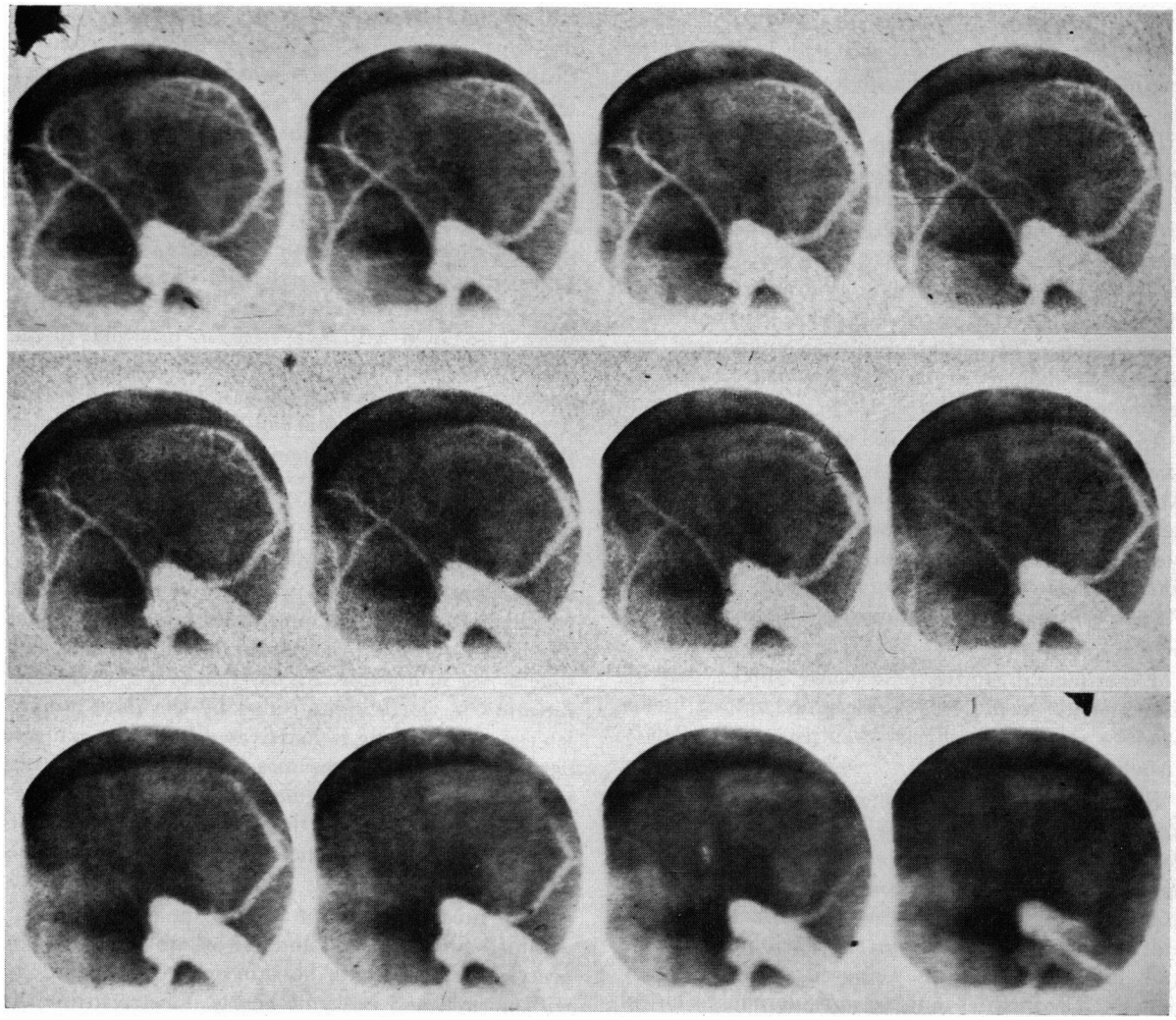

Figure 2.—Sequential frames from a 16 mm. cine angiogram of a dog showing progressive filling of the coronary arteries.

Using acetylcholine arrest, Arnulf[3] demonstrated decided spasm of the coronary arteries while the patient was suffering angina pectoris. Another examination, after the angina was relieved by a coronary vasodilatator, showed normal-appearing coronary arteries. It is interesting that this technique has demonstrated operable coronary occlusive disease in the absence of electrocardiographic changes.[4]

Although harmless in dogs, the safety of cardiac arrest angiography remains to be established in humans. Dotter and coworkers[7] reported a fatality resulting from the use of acetylcholine in a digitalized patient. In combination with digitalis, acetylcholine causes myocardial irritability rather than cardiac arrest. In the case reported by Dotter, irreversible ventricular fibrillation occurred. Lehman and coworkers[21] reported convulsions on several occasions when this technique was used. However, it is not clear whether the cardiac arrest or the contrast agent toxicity was responsible. While the group of patients reported by Arnulf[3] had no ill effects from the transient cardiac standstill, moderate bronchospasm occurred when the acetylcholine was given intravenously.

A possible disadvantage of the cardiac arrest method is that changes that occur during the cardiac cycle are not demonstrated. It has been noted for instance, that the left coronary artery becomes tortuous during systole and that the aortic diameter increases, giving a potential measure of arterial distensibility.[17]

The establishment of acetylcholine arrest arteriography awaits further clinical trial.

The combination of balloon occlusion and cardiac arrest has resulted in beautifully detailed coronary studies in dogs[11] and this method would seem safer than balloon occlusion alone for human application.

Motion Pictures

The anatomic and physiologic information obtainable from coronary angiography may be increased by cinefluorographic recording. We have used this method in the evaluation of cardiac arrest arteriography in dogs (Figure 2). Winter and Lehman[42] used cinefluorography to record acetylcholine arrest coronary angiograms as the animal was being rotated. A three-dimensional appreciation was obtained as the dog rotated through a full 180° cycle during the film sequence. Sloman[37] reported on the use of cinefluorography of the aortic valve and coronary arteries during cardiac arrest in humans. This technique will improve as larger image intensification screens are perfected.

Sones and coworkers[38] used x-ray motion pictures to show the areas of distribution of the major coronary vessels as they were serially opacified by contrast injected into the sinuses of Valsalva or into the individual coronary ostia.

The unsolved problem in coronary angiography is the toxicity of the available radiopaque contrast agents. Dotter advocated the use of thorium dioxide, which is free of the immediate toxic effects of the other agents and produces excellent opacification. However, it is very irritating if accidentally deposited in the soft tissues, and, being radioactive, probably has a long-term carcinogenic effect.[23] As other forms of contrast agents such as the heavy metal chelates[36] are investigated, a safer agent may be discovered.

Should a less toxic opaque material be developed and should transient cardiac arrest prove innocuous, coronary arteriography should become a routine diagnostic study for all patients suspected of having coronary artery disease.

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